Introduction to Botany. Lecture 19

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Outline

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Previous final question: the answer

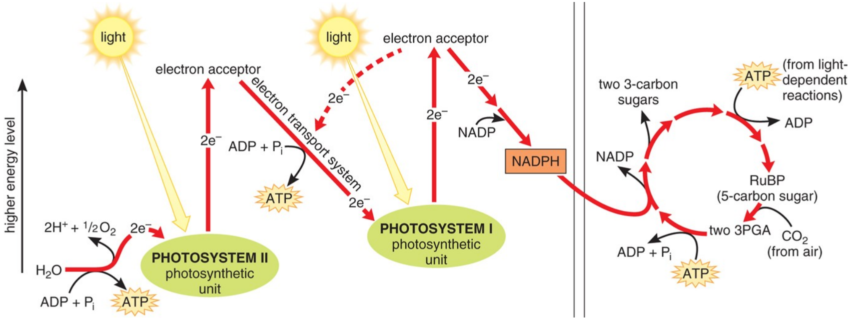
List more than one difference between light and enzymatic stages of photosynthesis

Previous final question: the answer

List more than one difference between light and enzymatic stages of photosynthesis

Light stage	Enzymatic stage
Produces NADPH, ATP	Uses NADPH, ATP
Needs light	Needs CO_2
Not a cycle	Cycle
...	...

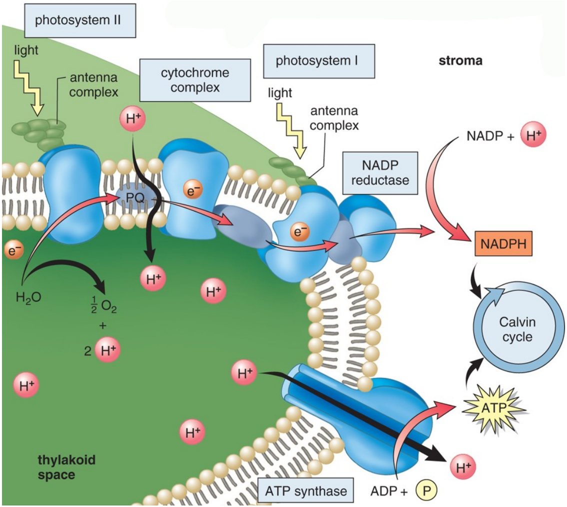
Light and enzymatic stages



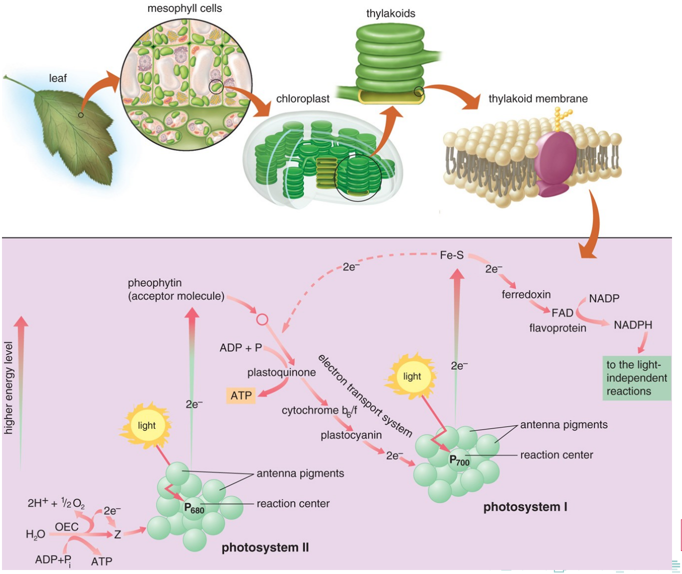
Results of the light stage

At the start	At the end
H_2O	H_2O (result of pump) and $\mathbf{O_2}$
Chlorophylls	Chlorophylls
ADP and P_i (inorganic phosphate)	ATP
$NADP^+$	NADPH

Light stage


photosystem II
light
antenna complex
cytochrome complex
photosystem I
stroma
light
antenna complex
NADP reductase
NADP + H+
H+
PQ
e−
e−
e−
NADPH
H2O
1/2 O2
+
2 H+
H+
H+
H+
H+
H+
Calvin cycle
ATP
thylakoid space
ATP synthase
ADP + P
H+

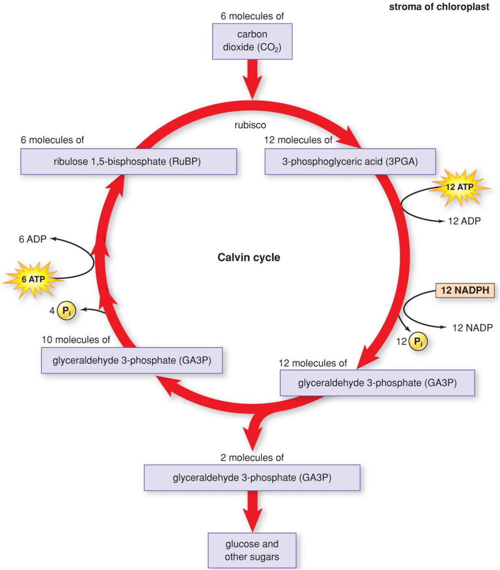
Two photosystems



Results of enzymatic stage

At the start	At the end
CO_2	$C_6H_{12}O_6$ (or other organic molecules)
NADPH	$NADP^+$ (and H to organic molecules)
ATP	ADP and P_i (inorganic phosphate)
C_5	C_5
Rubisco	Rubisco

Enzymatic stage



(GA3P=PGAL)

Photorespiration

Rubisco is two-faced enzyme, it catalyzes **photorespiration** if the concentration of O_2 and/or temperature is high

- O_2 + C_5 (ribulose biphosphate) $\xrightarrow{Rubisco}$ 3-phosphoglycerate $\longrightarrow$ CO_2 + PGAL + other molecules, e.g., NH_3 (through mitochondria)
- This is a sideway, wasteful process because it costs energy more than Calvin cycle, wastes C_5 and also produces toxic ammonia
- Photorespiration is said to be an evolutionary relic

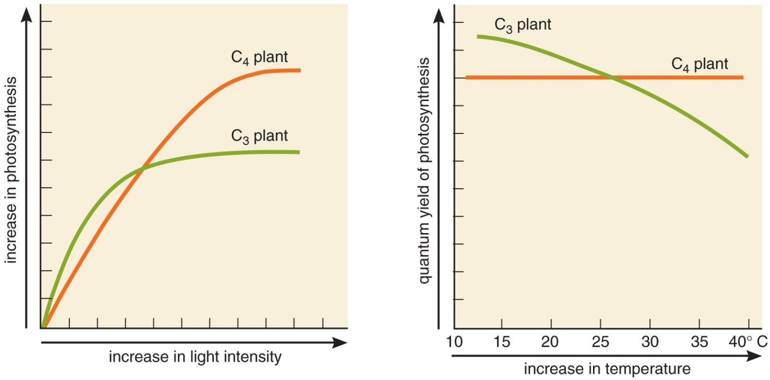
Minimization of photorespiration

To minimize photorespiration, plants need to increase concentration of CO_2:

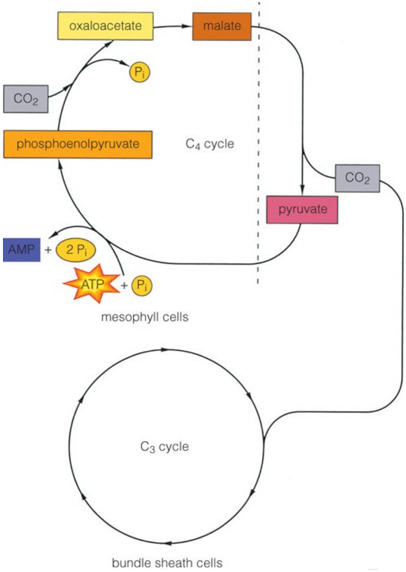
1. CO_2 + C_5 (PEP, phosphoenolpyruvate) $\xrightarrow{\text{PEP carboxylase}}$ C_4 (different organic acids), this is the temporarily accumulation of carbon dioxide
2. $C_4 \longrightarrow$ pyruvate + CO_2, the release of carbon dioxide will increase its concentration
3. Pyruvate + ATP $\longrightarrow$ PEP + AMP + 2P_i, the cycle costs ATP

Processes above called C_4 cycle, it is an addition to Calvin (C_3) cycle in order to increase concentration of CO_2

C_3 *versus* C_4


increase in photosynthesis
C4 plant
C3 plant
increase in light intensity
quantum yield of photosynthesis
C3 plant
C4 plant
10
15
20
25
30
35
40° C
increase in temperature

C_4 cycle

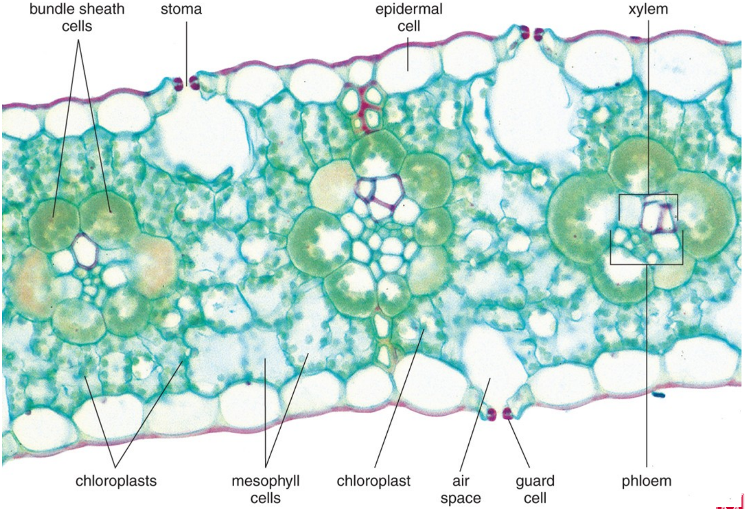

oxaloacetate
malate
P_i
CO_2
phosphoenolpyruvate
C_4 cycle
CO_2
pyruvate
AMP + 2 P_i
ATP + P_i
mesophyll cells
C_3 cycle
bundle sheath cells

C_4 and CAM plants

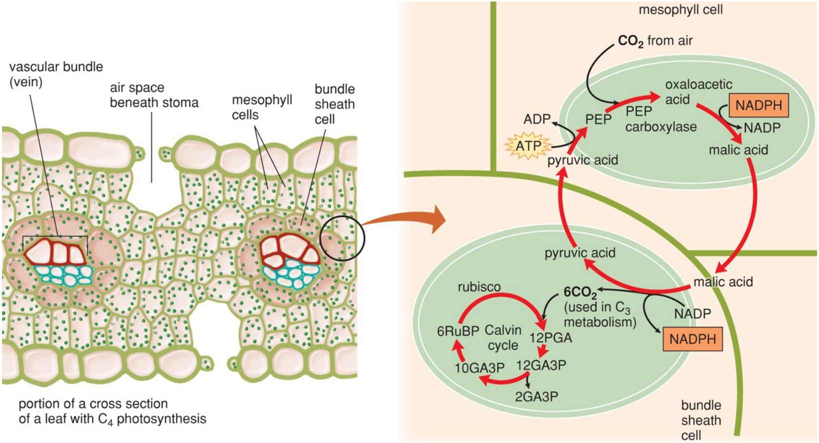
Two groups of plants have C_4 cycle:

- **CAM-plants** which drive C_4 cycle at nights:
  - This is a **temporal** separation between accumulation of CO_2 and photosynthesis)
  - CAM-plants (17,000 species, 7% of plant biodiversity) are mostly succulents from different orders and families (e.g., cacti—Cactaceae from Caryophyllales)
- **C_4-plants** which drive C_4 in mesophyll cells and C_3 in bundle sheath cells:
  - This is a **spatial** separation between accumulation of CO_2 and photosynthesis)
  - C_4-plants (7,300 species, 3%) are especially common among Poales (grasses order, e.g., corn) and Caryophyllales (pink order)

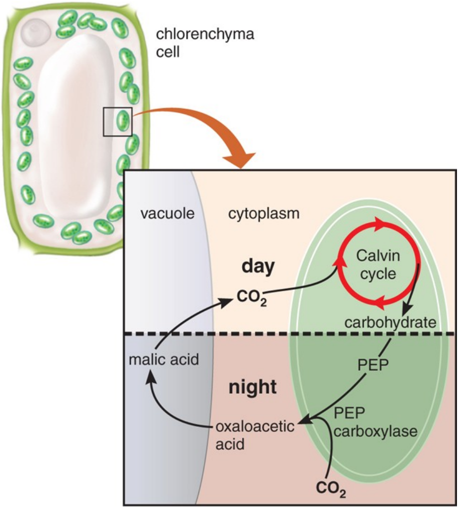
Leaf of C_4 plant



C_4


vascular bundle (vein)
air space beneath stoma
mesophyll cells
bundle sheath cell
portion of a cross section of a leaf with C_4 photosynthesis
mesophyll cell
CO_2 from air
oxaloacetic acid
NADPH
NADP
malic acid
PEP
PEP carboxylase
ADP
ATP
pyruvic acid
pyruvic acid
malic acid
rubisco
$6CO_2$ (used in C_3 metabolism)
NADP
NADPH
6RuBP
Calvin cycle
12PGA
10GA3P
12GA3P
2GA3P
bundle sheath cell

CAM


chlorenchyma
cell
vacuole
cytoplasm
day
CO_2
Calvin
cycle
carbohydrate
malic acid
PEP
night
PEP
carboxylase
oxaloacetic
acid
CO_2

Jade plant

CAM is named after the family Crassulaceae, to which Jade plant (*Crassula ovata*) belongs

Corn

Corn (*Zea mays*) is the C_4 plant, minimizing photorespiration at higher temperatures.

Summary

- To prevent wasteful **photorespiration**, plants “invented” the addition to photosynthesis, C_4 cycle
- **C_4** cycle accumulates and then releases carbon dioxide and therefore increases its concentration

Final question (2 points)

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Why plants need to avoid photorespiration?

For Further Reading

J. E. Bidlack, Sh. H. Jansky.
Stern's introductory plant biology. 12th edition.
McGraw-Hill, 2011.
Chapter 10.

Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy.
Plant Biology. 2nd edition.
Thomson Brooks/Cole, 2006.
Chapter 10.